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SOME SIGNALS OF SEISMIC ORIGIN RECEIVED AT PACIFIC SOFAR STATIO--ETC(U)
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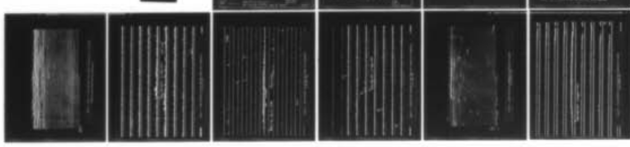

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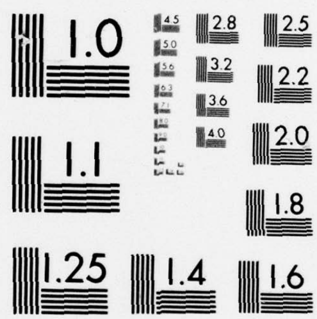

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SOME SIGNALS OF SEISMIC ORIGIN RECEIVED AT PACIFIC SOFAR STATIONS.

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prepared for the information of other members of the NEL staff

U. S. NAVY ELECTRONICS LABORATORY, SAN DIEGO 52, CALIFORNIA

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INTRODUCTION

It is not unusual for Sofar stations to receive signals from sources other than Sofar bombs, and it is well-known that some of these signals arise from seismic disturbances. The purpose of this memorandum is not to discuss all of the signals received at Sofar stations and known or believed to be due to seismic events, but rather to present the data on signals from three recent disturbances which had somewhat unique features. These three events were (1) the September 1952 eruption of Myojin Reef, a marine volcano located approximately 200 nautical miles south of Tokyo; (2) the Tulare Valley earthquake 21 July 1952, and (3) an earthquake of similar magnitude which occurred off the coast of Oregon on 20 August 1952. A detailed report of the Myojin eruption, which will contain data drawn from visual observations and tsunami recorders as well as from the Sofar stations, is being prepared by Dr. R. S. Dietz and the author. The present memorandum is concerned entirely with the Sofar data.

THE MYOJIN REEF ERUPTION, September 1952

On the 18th of September 1952 the U. S. Navy Sofar Stations at Point Sur and Point Arena on the coast of California received a series of signals of high intensity and particularly long duration. They were not received at the Kaneohe station, and consequently only a line of position for the source could be obtained. This line passed across the northern Pacific Ocean and through a point about 200 nautical miles south of Tokyo. Since the Kaneohe station had not received the signals, it was evident that the source had been somewhere west of the 180th meridian.

A few days later it was learned from Lt. G. W. Flickinger, Officer-in-charge at the Point Sur station, that the signals had sounded like a series of closely-spaced distant explosions, and that similar signals, although of lower intensity and shorter duration, were still being received. Since nothing like these particularly large signals had ever been recorded at the Sofar stations before, we could only hazard guesses and start making official inquiries as to the source of them. Within a few days, however, press releases carried the information that a Japanese fishing boat had observed a new marine volcano in eruption about 200 miles south of Japan on 17 September. It was evident that this volcano was the source of the unusual signals. This is believed to be the first time any signals received at Sofar stations have been identified as being of volcanic origin.

Because of his interest in seismic phenomena, the signals were brought to the attention of Dr. R. S. Dietz, NEL oceanographer, who wrote to Dr. K. Suda, Chief of the Japanese Hydrographic office, to get more detailed information on the location of the volcano and on any observed eruption times. Later press stories carried further information about the event, along with the news that the Japanese Hydrographic Survey Ship No. 5, the Kaiyo Maru, had been lost with all hands aboard while on a trip to observe the phenomenon. Life Magazine of 13 October carried a pictorial story of the activity.

Dr. Suda kindly replied to Dietz's letter giving the location of the volcano as 31°56.7'N, 140°00.5'E, and naming it "Myojin Reef" in recognition of the Japanese fishing boat which had first sighted the eruptions on 17 September. He also enclosed a Japanese press release which mentioned that the Kaiyo Maru had secured radio communication at 8 p.m. Tokyo time on the

23rd, and had not been heard from thereafter. Since dead reckoning would place the ship at the scene about noon on the 24th, Dr. Suda believed that the eruption which took the lives of the 31 men, including Drs. R. Tayama and T. Nakamiya, leading Japanese oceanographers, must have occurred shortly thereafter.

Dr. Dietz and the author made a detailed survey of the Sofar data in an attempt to fix the beginning and end of the activity, to determine the time of the fatal eruption, and in general to get an idea of the life history of such an event. Before going into this discussion, however, it may be worthwhile to digress for a moment in order to describe some features of a Sofar installation for the benefit of those unfamiliar with the subject.

A Pacific Sofar installation consists basically of a group of crystal hydrophones mounted in a stainless-steel cage and situated on the ocean floor at a depth of 350 to 400 fathoms. Several miles of U. S. Navy Type 115P submarine cable are used to connect the hydrophones to recording equipment on shore. At the shore end of the cable, the incoming signals are amplified, passed through a 500 cps lowpass filter, rectified, logarithmically compressed, and then recorded as power levels on a large sheet of paper mounted on a revolving drum. A timing trace is recorded adjacent to the signal trace and calibrated daily against official radio time signals in order to make possible the accurate determination of signal arrival times. On the reproductions of recordings in this memorandum the timing trace appears beneath the signal trace, and the timing marks are one second apart. Each horizontal trace on the recordings follows the preceeding one by slightly more than 7 minutes. The signals are also routed to a loudspeaker for purposes of aural monitoring.

The transmission of underwater explosive signals over long distances is made possible by the nature of the vertical sound velocity distribution in the deep ocean. The velocity decreases with depth until a minimum value is reached (at a depth of approximately 400 fathoms in the mid-latitude regions of the Pacific), and then increases with depth from this point to the bottom. This velocity structure results in the sound energy being refracted in such a manner that a certain portion of it is transmitted over deep ocean paths without suffering losses at either the surface or bottom. Shoal regions along the path, caused by seamounts, continental slopes, etc., will of course intercept some of the energy and thereby affect the shape and intensity of the received signal.

The intensity of this "channelled" sound decreases only as the first power of the range, plus an absorption factor. Since the absorption in the low-frequency region is small, it is possible to detect an explosive signal in the ocean at great distances.

Returning now to the survey of the Sofar data, if we allow for a travel time of 1 hour 37 minutes 32 seconds from the source to the Point Sur station, based on an assumed average horizontal velocity of 4830* ft/sec, and a computed distance of 4650 nautical miles, the time of the first large eruption can be placed at

* A value of 4850 ft/sec is used for triangulation purposes in the NE Pacific Sofar Network. A lower value has been assumed here since the major portion of the travel path lies in the northern part of the Pacific where the velocity at the sound channel axis varies from about 4810 to 4840 ft/sec.

0012 GCT on 16 September. This would be 0912 a.m. Tokyo time. A much weaker signal originated at 1540 GCT on 15 September, and there may have been rumblings prior to this that were too weak to be detected at the distant Sofar stations. The major activity, as far as detection at the Sofar stations was concerned, ended on 26 September with a large eruption at 0334 GCT.

Figure 1 is a plot of the approximate signal intensity at the Point Sur station as a function of the time the signals were received. The intensity scale used here is a qualitative and rather crude one based simply on a visual estimate of the signal-to-noise ratio. A value of 1 indicates a signal-to-noise ratio of less than 10 db, 2 indicates the ratio was estimated to be 10-20 db, 3 20-40 db, 4 30-40 db, and 5 represents a signal-to-noise ratio greater than 40 db. Although only 66 lines are shown on Figure 1, well over 400 signals were received at the stations, since many of the points shown on the figure indicate a series of from 2 to 50 signals occurring during intervals as long as 90 minutes. Only those signals are shown that could be identified on the records at both the Point Sur and Point Arena stations.

A fairly complete history of the volcanic activity can be obtained from Figure 1. The activity probably began with some small eruptions, only one of which, on 15 September, was strong enough to be detected at the Sofar stations. The 16th saw the outbreak of the major eruptions and was followed by a quiet interval on the morning of the 17th. Beginning about 1200 GCT, 17 September, there occurred a 12-hour period of rather heavy activity which in turn was followed by about 9-10 hours of quiet. This interlude was broken by a series of tremendous explosions which initiated a 28-hour period during which the volcano was in almost continuous eruption. The signals received during the periods 0950-1015 and 1225-1350 GCT on the 18th were the ones that first caught our attention and are shown on Figures 2 and 3. The combination of high intensity and long duration makes these signals totally unlike any ever received before at the Sofar stations.

After a relatively quiet 15-hour period, there followed an interval of almost equal length during which there were many large eruptions. Beginning on the 21st the explosions, although still large, began to be less frequent, and finally, after a 48-hour period during which only four eruptions occurred, the major activity ended with a large explosion. It is quite possible, of course, that there was some minor activity on succeeding days. No more signals were detected, however, until 2 October when moderate sized signals were received at 1245 GCT and 1921 GCT. No activity was evident after 2 October.

From the standpoint of total energy, the signal starting at 1250 GCT, 18 September (see Figure 3), and lasting for 33 minutes is the largest ever received at a Pacific Sofar station. The peak sound level of the signal was 13 db above 1 microbar, and, although signals of higher sound level have been received, none have ever approached this one in duration. Rough computations indicate that the sound energy in the 20-500 cps frequency band released to the water during this interval was of the order of at least 10^{16} ergs.

On the basis of the data shown on Figure 1, the eruption which apparently destroyed the Kaiyo Maru took place at 0320 GCT on the 24th. This would be 1220 p.m. Tokyo time, and thus bears out Dr. Suda's belief as to when the catastrophe occurred. This eruption did not produce an unusually large acoustic signal (intensity 3 on the scale used here), but the Kaiyo Maru

was evidently very close to the volcano at the time of the explosion. A communication from Dr. Dietz, who is in Japan at the time of this writing, states that volcanic rock was found embedded in some of the planks of the Kaiyo Maru which were later recovered. Since this explosion had been preceded by a period of several hours during which no explosions occurred, it was probably thought safe to make a close approach to the volcano.

According to Life Magazine of 13 October, the new islet was 100 feet above water, 500 feet long and 350 wide on 18 September, and was pouring molten rock into the sea around it. Life further stated that the volcanic peak apparently blew into bits and subsided back into the sea on 23 September, and it was implied that the Kaiyo Maru had been sunk on this date by one of the last explosions of the volcano. The evidence from the Sofar data is that the disaster occurred on 24 September, Tokyo time (still the 23 rd in the U.S.), and the volcano was certainly active on the 25th and 26th of September.

The success of the Sofar stations in getting as complete a record of the life of the volcano as that shown on Figure 1 leads naturally to speculation as to how useful such installations may be for detecting similar activity in the future. Certainly the signals shown on Figure 2 and 3 are very unusual and distinctive, and if similar signals are ever received again, it might reasonably be supposed that a marine volcano is in eruption somewhere within the limits of reception of the station. If three stations received the signals the location of the source could of course be determined.

Many of the signals received from the Myojin volcano, however, were not so different from some other types of signals as to be readily recognizable. T-phases from earthquakes, for example, have features in common with some of the signals received from Myojin, and some of the weaker Myojin signals resembled Sofar signals originating in the high northern latitudes. The Kaneohe station frequently receives signals very similar to some of the Myojin ones, but the sources of them are still undetermined since it has not been possible to correlate them with any reported seismic or explosive disturbances. It may be, however, that they are associated with underground or undersea rumblings in the Hawaiian Island region.

It is also worth noting in this regard that it was not possible to correlate any signals at Kaneohe with known eruptions of the San Benedicto Island volcano (see Life Magazine, 29 September 1952, p. 37, or Time Magazine, 29 September 1952 p. 70), for pictorial stories of this event). Many unidentified signals were received at the Kaneohe station during the period of eruption, and some of these may have been caused by the volcano. Yet, on the very few occasions when eruption times were known, no signals were discernible. The observed eruptions may not have put sufficient energy into the sea to be detected at a distant Sofar station, or there may be a seamount between San Benedicto Island and Kaneohe which prevents transmission to Kaneohe. In any case, however, it would seem premature at the present time to use Sofar stations as the alerting agency of marine volcanic activity unless signals nearly as distinctive as these of Figures 2 and 3 were received. More information on the characteristics of volcanic signals, and how they differ from T-phases, etc., seems necessary.

THE TULARE VALLEY EARTHQUAKE OF 21 JULY 1952

Turning now to another seismic event, a much publicized earthquake occurred in Southern California at 1152:11.5 GCT, 21 July 1952. It has been referred to in the press as the Tehachapi quake, but USC&GS Preliminary Determination of Epicenter Card No. 97-52 designates it the Tulare Valley quake and gives the epicentral location as 35.1°N, 118.9°W. It was of magnitude 7 1/2, and caused considerable property damage in the Kern County area.

The Sofar stations at Point Sur and Kaneohe both received signals from this quake. The Point Sur hydrophones are located 320 kilometers from the epicenter and the signal was received at 1152:58.7. Since no water path is involved here, this gives a travel velocity through the earth of 6.86 km/sec. which agrees well with the value of about 6.5 km/sec. given by B. Gutenberg for velocities of longitudinal waves in Southern California at a depth of about 6 kilometers.[1] The signal recorded by the hydrophone at Point Sur at a depth of 400 fathoms is shown in Figure 4. It has a peak sound level of -14 db vs 1 microbar.

The signal received at Kaneohe, a total distance of 4059 kilometers from the epicenter, is shown in Figure 5. It reached a peak sound level of -19 db vs 1 microbar and was judged to be first discernible above background noise at 1236:01.2 GCT. Using this as the time of arrival, a mean velocity of 4855 ft/sec., which unpublished work here indicates is the best value for deep-sound-channel transmission in the mid-latitude regions of the Pacific, and a velocity of 6.86 km/sec for the land path, results in a calculated land path of 213 kilometers. This takes us to the region of the 400-fathom contour on the great circle path from the epicenter to Kaneohe, and indicates, as was suggested by Tolstoy and Ewing[2], that the sound energy is coupled into the ocean along the continental slope. The signal received at Kaneohe is, of course, a T-phase, discussions of which have been given by Ewing and others[2,3,4].

The signal received at Point Sur was not noticed by the station operator at the time. This can be taken to mean either that it sounded little different from some of the other anomalous noises received at such stations, or that the signal energy was primarily in the frequency region below 60 cycles per second and was therefore n t reproduced by the loudspeaker system. The signal received at

1. B. Gutenberg, "Waves From Blasts Recorded in Southern California," Trans. Amer. Geophysical Union, Vol 33, No. 3, pp 427 June 1952.

2. I. Tolstoy, and M. Ewing, "The T-Phase of Shallow-Focus Earthquakes," Bull. Seismological Soc. Amer. Vol 40, No. 1, p. 25, Jan 1950.

3. M. Ewing, F. Press, and J. L. Worzel, "Further Study of the T-Phase," Bull. Seismological Soc. Amer. Vol 42, No. 1, p 37, Jan 1952.

4. L. D. Leet, D. Linehan, and P. Berger, "Investigation of the T-Phase," Bull. Seismological Soc. Amer. Vol 41, No. 1, p 123, Jan 1951.

Kaneohe was noticed by the station operator, and Figure 5 shows that he recorded at the time that it was inaudible. This is good evidence that the signal energy lay in the low-audio, or perhaps upper sub-audio, frequency region. Small T-phase signals are frequently inaudible on the station loudspeakers, and this may provide a distinguishing feature between small T-phases and small signals from eruptions of marine volcanos.

The location of this earthquake, the ratio of land-to-water velocity, and the configuration of the west coast all combine to provide an interesting feature in regard to the signal received at Kaneohe. Energy could have travelled from the epicenter to points along the west coast from Point Conception to Cape Mendocino, and thence been reradiated so as to arrive at the Kaneohe station within a total interval of less than 30 seconds. For example, the total travel time along the path from the epicenter to Point Conception to Kaneohe is 2636 seconds, that from the epicenter to Cake Mendocino to Kaneohe is 2625 seconds, and that from the epicenter to Point Arena to Kaneohe is 2613 seconds. Thus, to a receiver located at Kaneohe, this entire 800 kilometer stretch of the west coast would seem to be the source. Had it not been for this circumstance, a much weaker signal might have been received at Kaneohe.

Whether or not a signal was received at the Point Arena station is somewhat uncertain. The hydrophones are located 618 kilometers from the epicenter so, on the basis of a 6.86 km/sec. land velocity, the signal should have arrived at 1153:41.6. A small signal, see Figure 6, was received 1 min. 2 secs. earlier, and it may be that an error of 1 minute was made by the station operator in logging the time on the data sheets. Such errors, although rare, have been known to occur. On the other hand, the signal shown on Figure 6 may have been caused by an anomalous burst of noise of different origin.

Several aftershocks of this earthquake ranging in magnitude from 5 to 6½ were recorded by seismological stations, but an inspection of the Sofar records revealed no clear-cut signals from any of these aftershocks. Certainly no signals were received from shocks of magnitude 6 or less, and in the case of the two shocks of magnitude 6¼ (0703:45 GCT 29 July and 1209:08 GCT 31 July), no signals were received at Point Arena or Kaneohe, while at Point Sur equipment difficulties were being experienced at the time of the first of these shocks, and only the faintest indication of a signal was discernible at the predicted time of arrival of a signal from the second shock. It is not at all unlikely that this latter "signal" was merely a small noise burst that happened to occur near the predicted signal-arrival time.

Considering the level of the signals received at Point Sur and Kaneohe from the main quake, Figures 4 and 5, it is not surprising that signals from aftershocks were not detected, since a one unit decrease in earthquake magnitude signifies a 63-fold decrease in energy[5]. This would result in the signal from a magnitude 6½ aftershock being 18 db lower than that of the magnitude 7½ main shock. Even a slight increase in the background noise could prevent such a signal being detected.

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5 Principles Underlying the Interpretation of Seismograms by F. Neumann, U.S. Coast & Geodetic Survey Special Publication No. 254, p 33 (1951).

THE EARTHQUAKE OFF THE COAST OF OREGON ON 20 AUGUST 1952

The final seismic event to be discussed here is included primarily for comparison with the signal of Figure 5. The signal shown at the top of Figure 7 was received at the Kaneohe Sofar Station from a magnitude $7\text{-}7_4$ earthquake occurring at 43°N, 127°W at 1524:59 GCT 20 August 1952[6]. This location is off the coast of Oregon, 3619 kilometers from Kaneohe, and some 350 kilometers north of the Mendocino escarpment. It is obvious from Figures 5 and 7 that, although the magnitudes of the initial disturbances were comparable, a far greater amount of energy was coupled into the water from the earthquake of 20 August than from that of 21 July. From the standpoint of the combination of peak sound level and duration (14 db vs one microbar and $11\frac{1}{2}$ minutes), the signal on Figure 7 is the largest T-phase ever recorded at a Pacific Sofar station.

The total travel time to the beginning of the signal of Figure 7 is 2451 seconds, and the range from the epicenter to Kaneohe is 3619 Kilometers. This gives an average velocity of 1.477 km/sec (4846 ft/sec), and indicates that the major portion of the energy entered the water at the site of the quake without first travelling through a horizontal land path and thus suffering considerable attenuation. Such a situation is quite possible, since, according to Hydrographic Office Chart No 5486, the epicenter is beneath a bread sloping plateau which constitutes part of the continental slope. This plateau drops gently in a westward direction from 1400 fathoms to the deep ocean floor, and culminates to the south at the edge of the Mendocino escarpment[7]. Energy from a shallow-focus earthquake could thus have been radiated as acoustic energy in the ocean in the vicinity of the site. Had the quake occurred beneath a flat ocean bottom, however, it is unlikely that much energy would have been propagated through the ocean[8].

No signal was received at the Point Sur station because the site of the quake was outside the arc of reception of the station. A signal was received at the Point Arena station, however, and is shown on Figure 8. (The blank spaces in the signal channels on the right-hand side of this figure were caused by a temporary flaw in the recording apparatus.) The peak sound level was -16 db vs 1 microbar, and the arrival time was taken to be 1530:49.6 GCT. Since the range from the site of the quake to the station is 522 kilometers, this gives an average velocity of 1.489 km/sec, or 4885 ft/sec, indicating again that the total travel was by means of the water path.

The lower sound level of the signal at Point Arena compared to that at Kaneohe can be accounted for by the nature of the respective travel paths involved. The sound energy travelled to Kaneohe by an entirely deep water path, greater than 1700 fathoms all the way. The energy was thus propagated with an average horizontal velocity characteristic of deep sound channel transmission, and without suffering much from losses due to bottom reflections. The route to Point Arena is a different matter, however. Approximately the first two-thirds of the path is over an almost flat bottom with the water depth averaging about 1600-fathoms. The bottom

6. USC&GS Preliminary Determination of Epicenter Card No. 111-52, 21 Aug 1952.

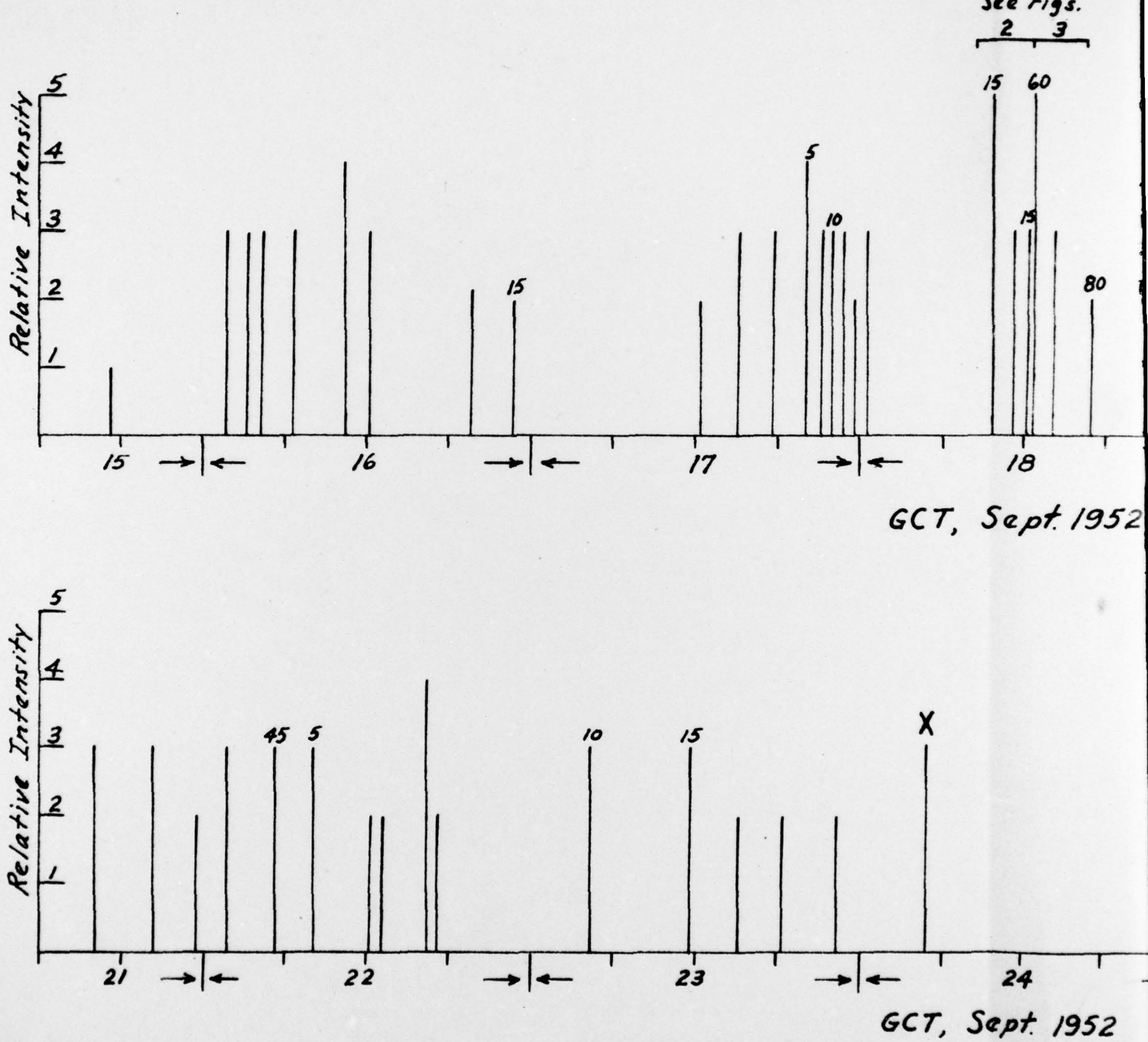
7. H. W. Menard and R. S. Dietz, "Mendocino Submarine Escarpment," Jour. of Geology, Vol 60, No. 3, p. 266, May 1952.

8. Frank Press, Maurice Ewing, and Ivan Tolstoy, "The Airy Phase of Shallow-Focus Submarine Earthquakes," Bull. Seismological Soc. Amer., Vol 40, p.111, 1950.

then rises at the shoreward end of the escarpment, and the remainder of the path consists of a slantwise traverse up the continental slope. The initial flatness of the bottom in the direction toward Point Arena would not be conducive to coupling energy into the ocean, and what energy was transmitted toward Point Arena would suffer from bottom reflections while crossing the continental slope. The effect of a sloping bottom on the duration and intensity of Sofar signals transmitted in the deep sound channel has been discussed in detail elsewhere[9].

The great variation shown here in the duration and intensity of T-phases recorded at Sofar stations from comparable earthquakes makes it clear that such signals cannot be used at present to give a reliable estimate of earthquake magnitude. The duration and intensity of the T-phases depend markedly on the location of the earthquake, and on the nature of the travel path to the receiver; much more so apparently than on the magnitude of the quake.

9. T. P. Condron, "The Effect of Sound Channel Structure and Bottom Topography on Sofar Signals," USNEL Report No. 233, 19 April 1951.

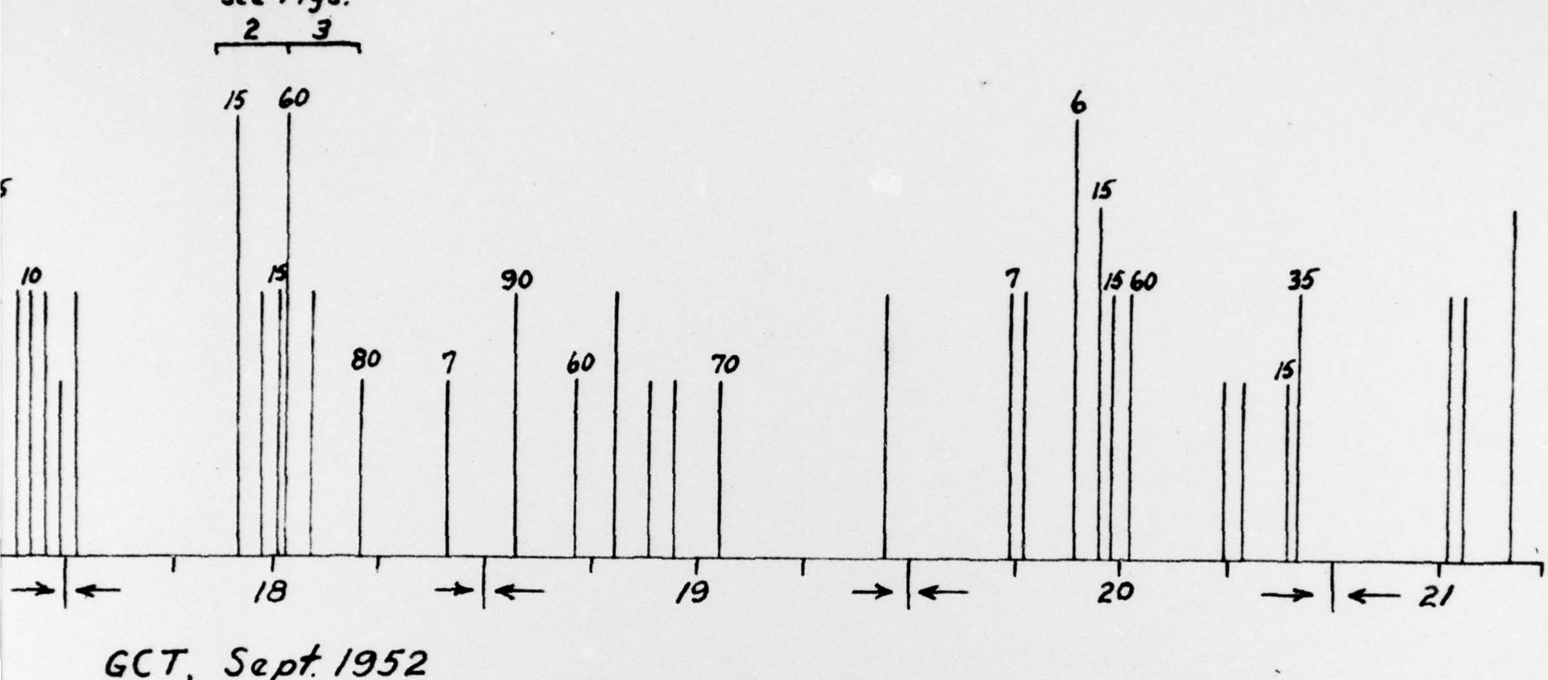


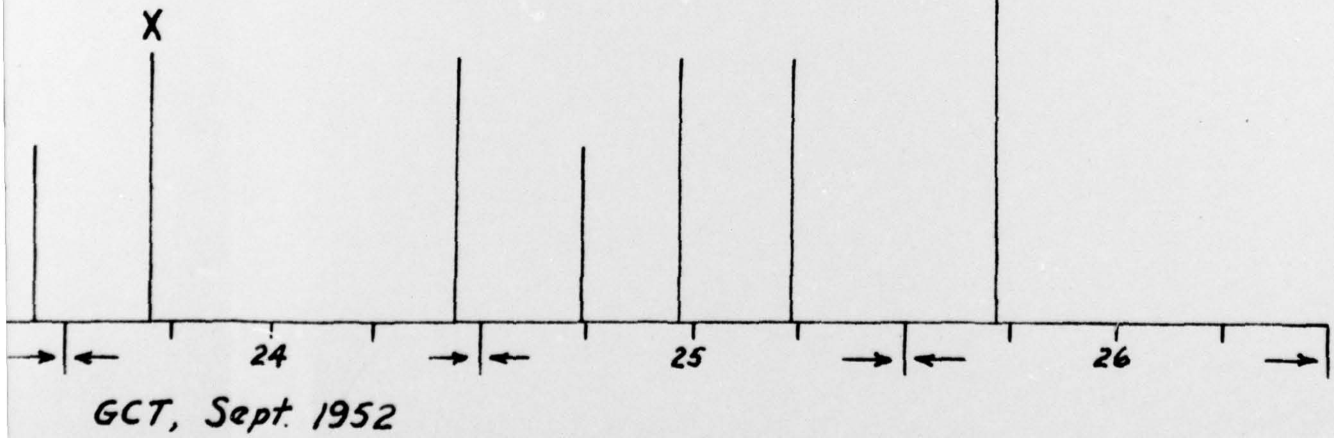
SIGNAL INTENSITY VS ARRIVAL

Numbers above lines indicate approximate d
during which several signals

X - Signal from eruption believed

FIGURE 1





NSITY VS ARRIVAL TIME AT POINT SUR

indicate approximate duration, in minutes, of intervals
vhich several signals were received.

n eruption believed to have sunk Kaiyo Maru

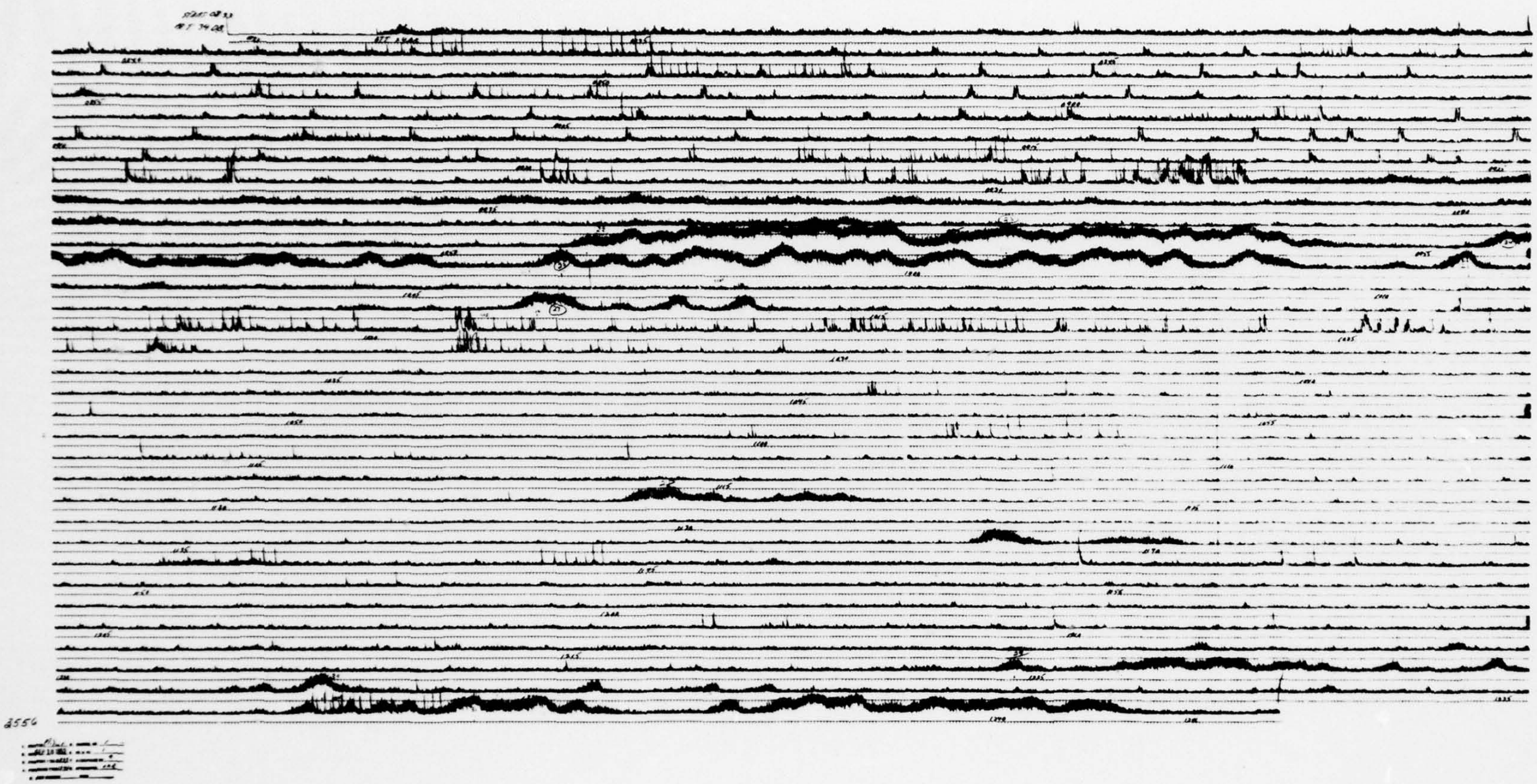


Figure 2. RECORD AT POINT SUR SOFAR STATION DURING 0833-1241 GCT, 18 Sept 52

First intensity 5 signals received are those shown near the center. Period of most intense activity begins near the bottom.

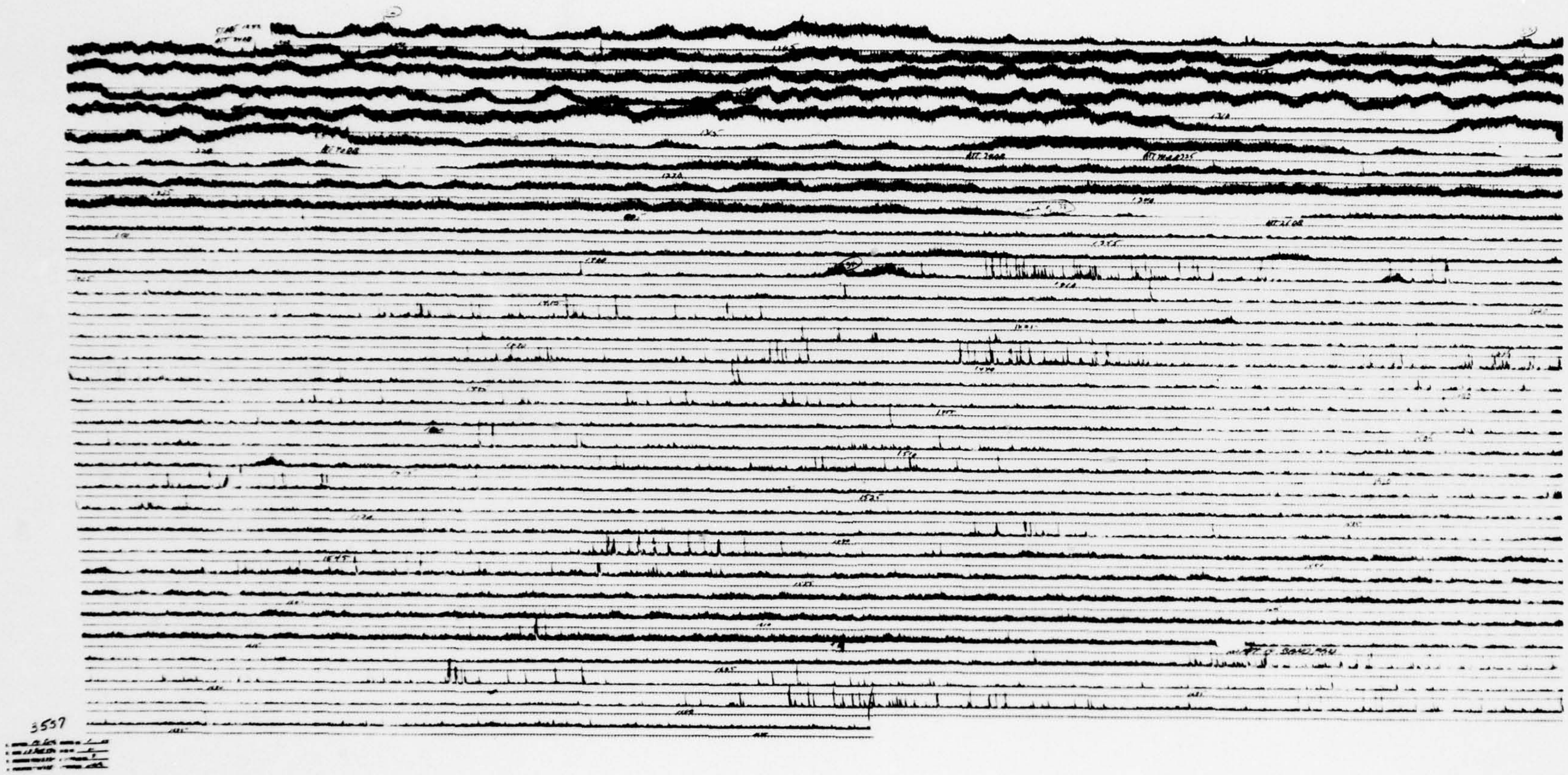


Figure 3. RECORD AT POINT SUR SOFAR STATION DURING 1242-1648 GCT, 18 Sept 1952

Period of most intense activity shown at top.

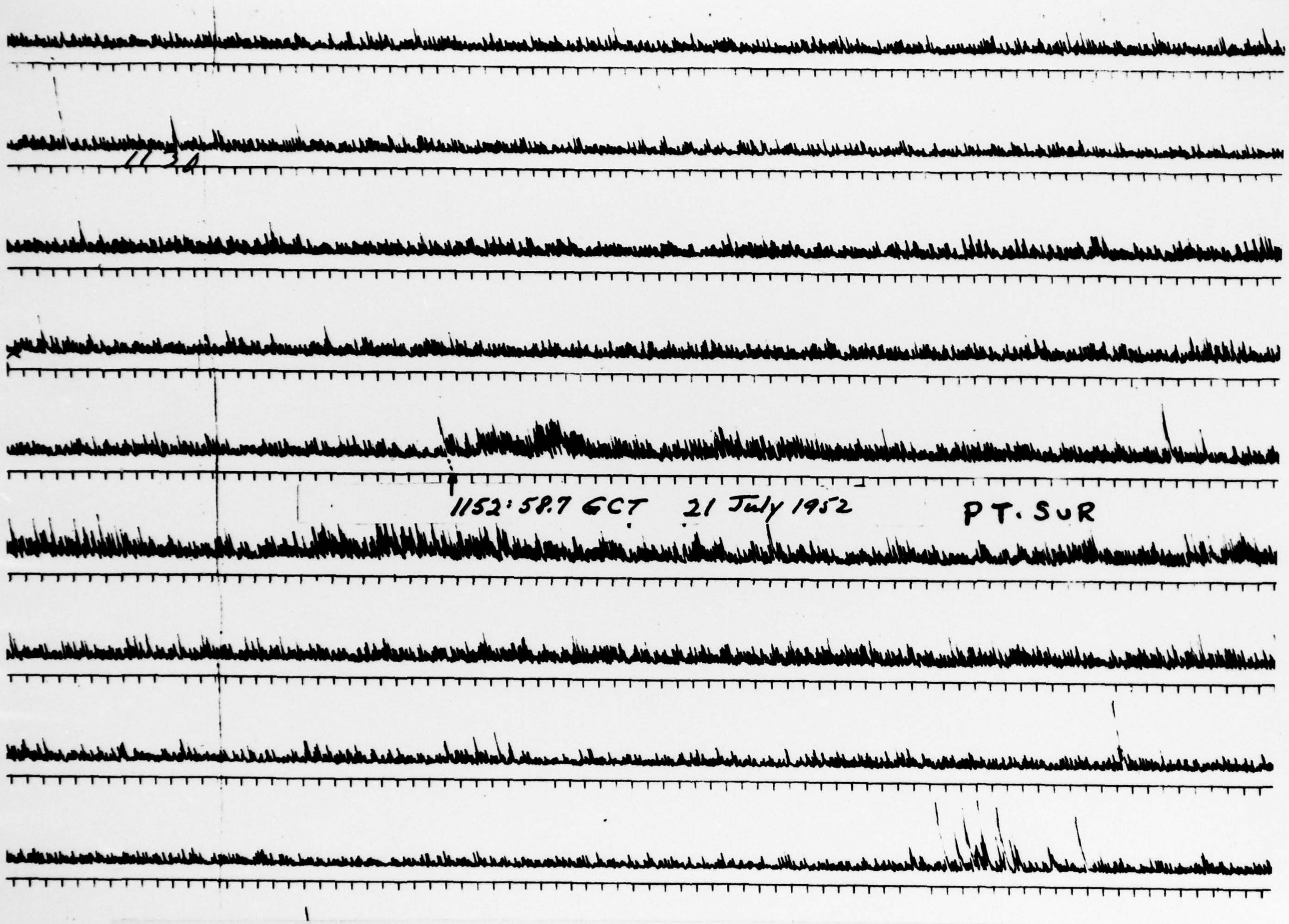


Figure 4. SIGNAL RECEIVED AT POINT SUR FROM TULARE VALLEY EARTHQUAKE OF 21 JULY 1952

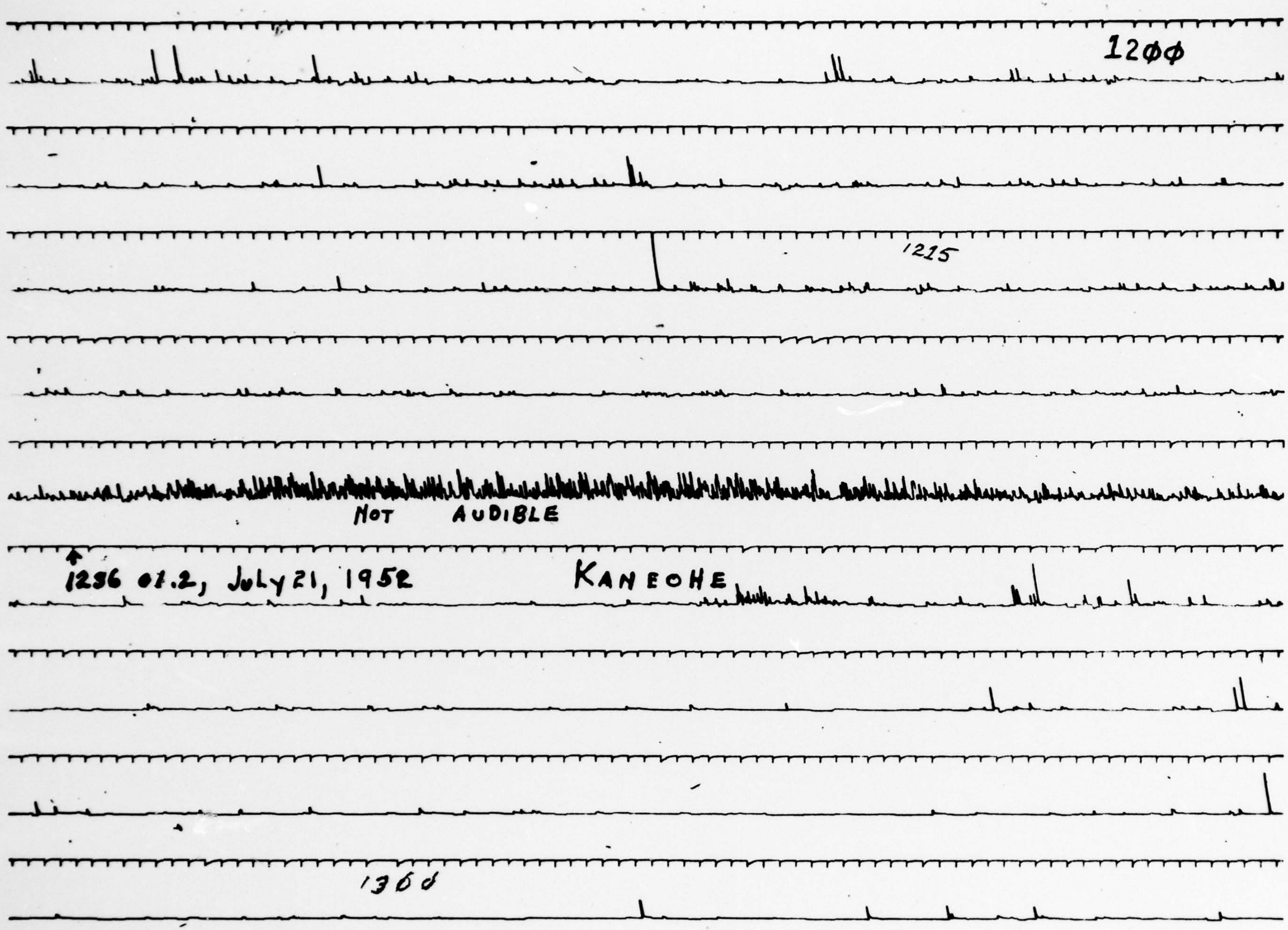


Figure 5. SIGNAL RECEIVED AT KANEOHE FROM TULARE VALLEY EARTHQUAKE OF 21 JULY 1952

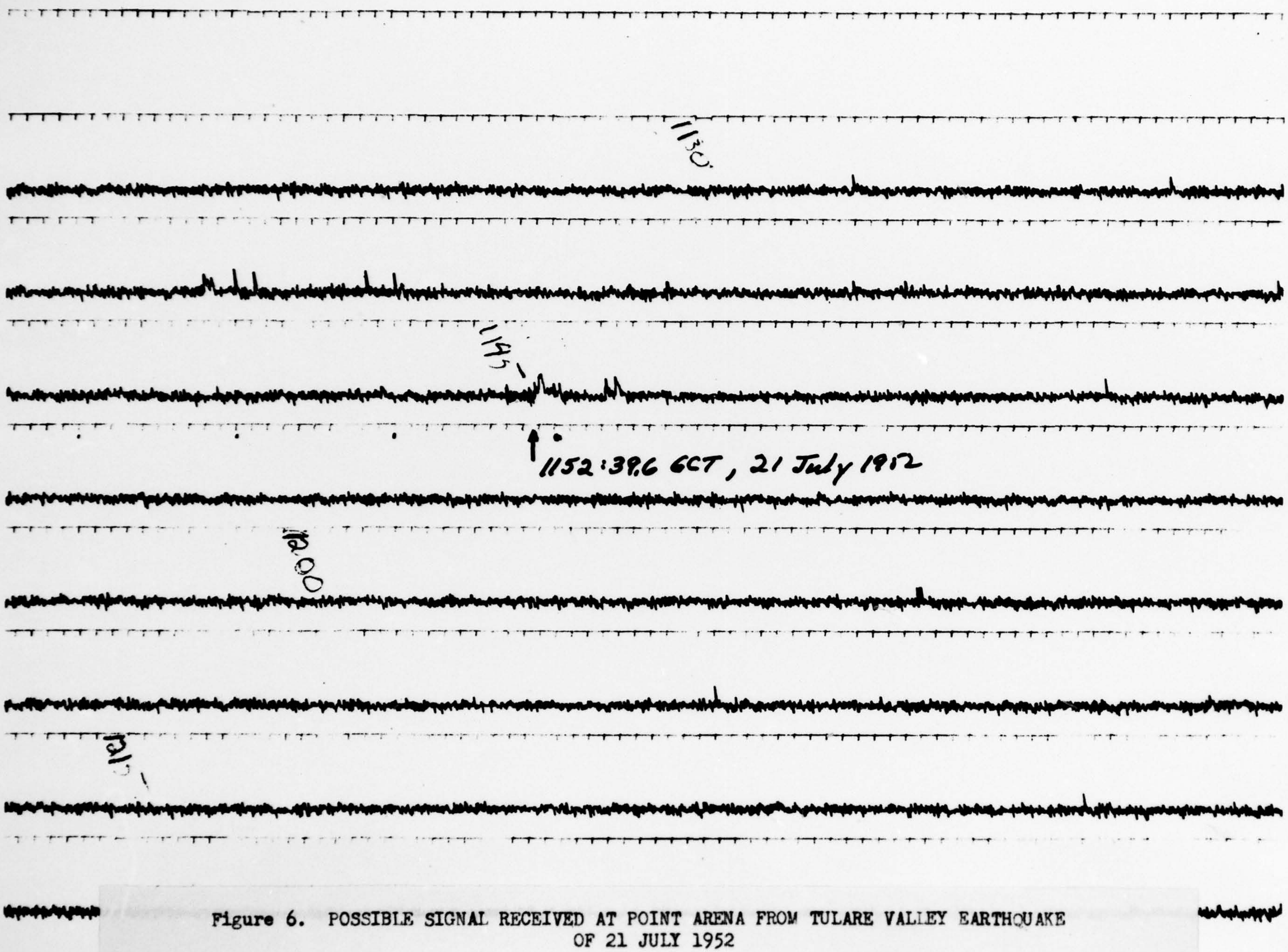


Figure 6. POSSIBLE SIGNAL RECEIVED AT POINT ARENA FROM TULARE VALLEY EARTHQUAKE OF 21 JULY 1952

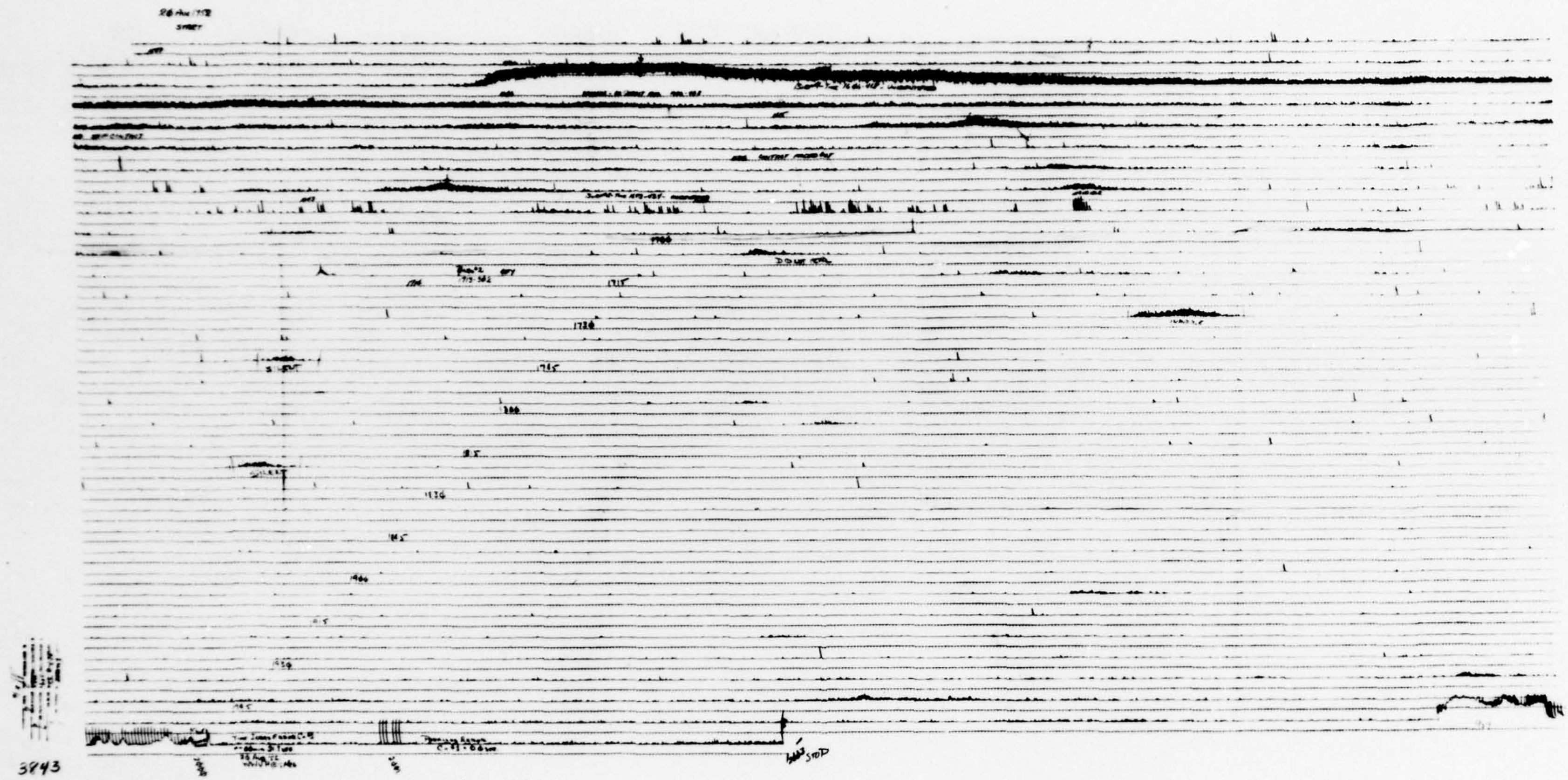


Figure 7. SIGNAL RECEIVED AT KANEOHE FROM EARTHQUAKE OFF OREGON ON 20 AUGUST 1952

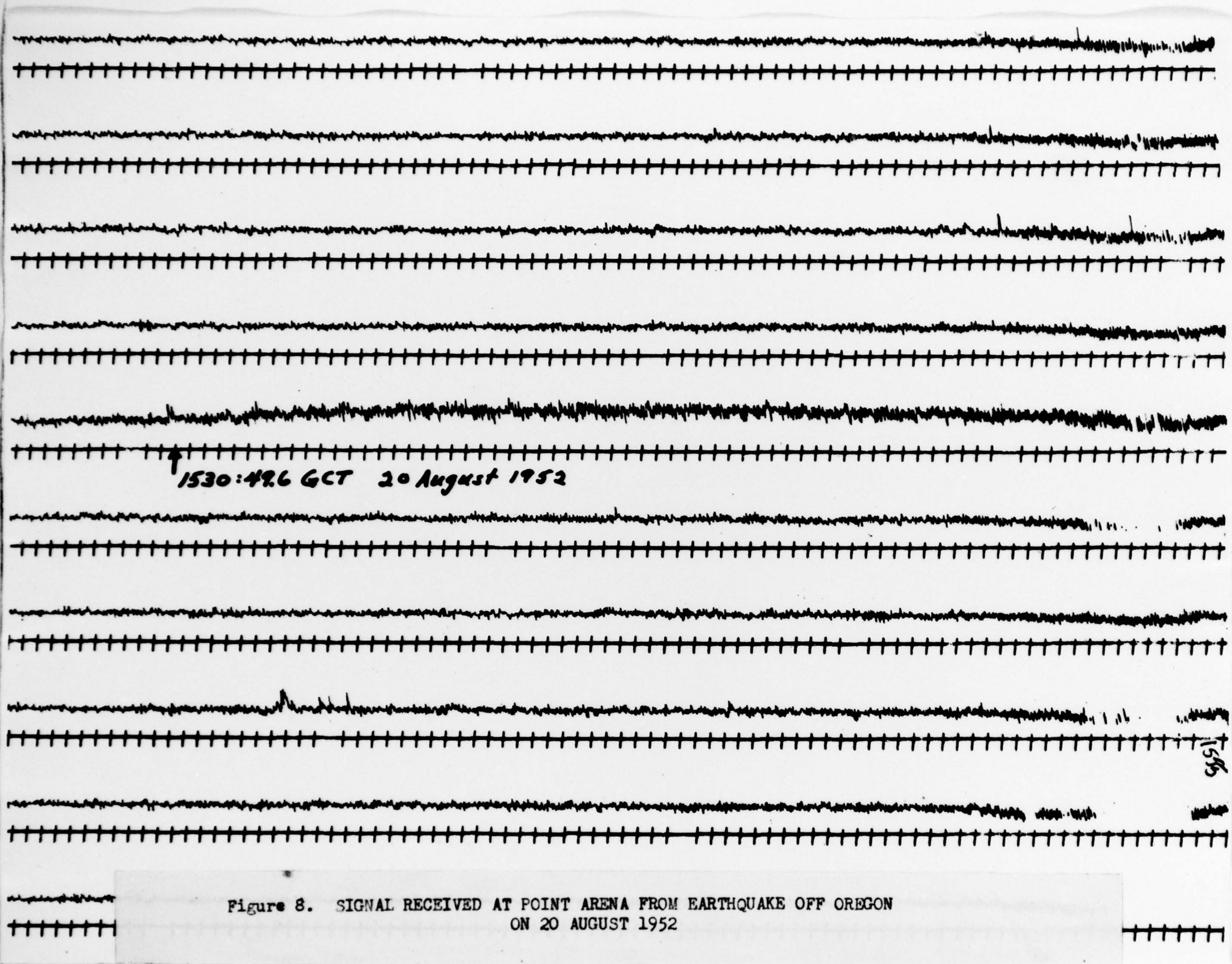


Figure 8. SIGNAL RECEIVED AT POINT ARENA FROM EARTHQUAKE OFF OREGON ON 20 AUGUST 1952